Investigating Into How Video Gaming Affects Sleep and Alter Brain Structures During Childhood

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Abstract

The video game industry is growing, and video games are a big part of many people's everyday lives, but it is an area that has not been studied enough to know the biological effects. The aim of this study was to investigate how video games affect sleep longitudinally by a two-year follow-up, and brain structure cross-sectionally. The data was obtained from two questionnaires, The Sleep Disturbance Scale for Children (SDSC) and ABCD Youth Screen Time Survey (STQ), and magnetic resonance imaging (MRI) scans. The data was then analyzed with multiple linear regression. The result indicates that video gaming does not alter brain structure (β = 298.7881 [-2703.526 – 3301.102] P = 0.845), but affects sleep in children both at baseline (β = 0.8109 [0.611 – 1.011] P =0.000) and two years later (β = 0.1958 [0.032 – 0.360] P = 0.019).

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Contents

1 Introduction

Since the introduction of the first video game '*Spacewar!*' by Steve Russel in 1962 at the Massachusetts Institution of Technology, video games have upgraded immensely (id est, from simple graphics and radiant dots moving on the display to delightful experiences rich in details) [1]. Data from 2020 showed that the total amount of video gamers in the world was 2.7 billion, and video games are extremely popular amongst children [2].

Previous studies have reported that regular gaming can be beneficial as it increases the volume of grey matter and stimulates brain connectivity, and therefore improves intellectual- and social skills, physical performance and relieve mental illness such as depression and anxiety [3, 4, 5]. However the problem occurs when spending too much time playing video games, and it becomes an addiction [2]. In the 11th Revision of the International Classification of Diseases (ICD), World Health Organization (WHO) recognized gaming disorder as a behavioural addiction and mental health disorder, and it has been observed that the dopamine release of game addicts is equivalent to drug abusers [6, 7]. The known consequences of a gaming disorder are anxiety, depression, attention deficit hyperactive disorder (ADHD), social phobia, sleep problems, and inadequate psycho-social support [2].

1.1 Importance of sleep during childhood

Sleep is necessary for our body to function and maintain homeostasis [8]. Parts of the brain (id est, medial prefrontal cortex, insula, amygdala, and inferior frontal gyrus) are active during sleep, performing many important functions to process information and recover [9, 10, 11], İn children, the quality of sleep is more important as they are in the development phase of the body and brain. During sleep, the brain sorts and stores information, and produces hormones and other chemicals that are important to grow [8].

Previous studies on video games and their correlation to sleep have shown that video gaming can cause bad sleep quality, fatigue, and insomnia resulting in altered brain architecture, physiological indices, and temporal structure. [7]

External stimuli such as video games before going to bed can affect the ability to fall asleep [1]. Video games stimulate the state of CNS arousal, since they affect heart rate, blood pressure, and respiratory rate so that they increase [12, 13]. This also affects sleep quality negatively and decreases sleepiness before sleeping [14, 15]. Additionally, the blue light from the screen blocks the release of melatonin, which counteracts sleep and increases SOL - the time it takes to fall asleep [16]. All the factors listed above lead to less sleep time. [5].

1.2 Brain Development

The structure and function of the brain is dynamic and changes through life. The brain grows faster than the rest of the body and each tissue of the brain has a different developmental trajectory. For example, the volume of the grey matter peaks around eight years of age, whereas the volume of white matter peaks until early adulthood. In general, the brain volume increases initially and then declines slowly after eight years of age. However, it should be noted that it can be affected by our genome and environmental factors. Brain maturation is important for health, but changes in brain substances will disturb it. This can lead to disabilities and disorders. [17]

1.2.1 Hippocampus

The structure of the hippocampus is like a sea horse, and it is located deep in the temporal lobe [18]. Hippocampus is a part of the limbic system and is responsible for learning, long-term memory and extinction and recovery of fears [19].

1.2.2 Medial Prefrontal Cortex

The medial prefrontal is located in the front part of the frontal lobe of the brain. It is active during memorization, reward-guided learning, and decision-making by anticipating emotions [20].

1.2.3 Insula

The insula is a brain region located deep inside the brain, in the lateral sulcus and is connected to the limbic areas (id est, amygdala, hippocampus, prefrontal cortex). The insula is essential for the autonomic nervous system and responds to environmental changes by external sensory information, which is combined with information from different parts of the body from internal emotional and bodily state signals [21]. The information is then coordinated and passed on to brain regions in DMN which includes medial prefrontal cortex, posterior cingulate cortex/precnus and angular gyrus, and CEN which mainly consists of the prefrontal cortex. For example, the insula reports negative emotions from processes in the body, and emotional stimuli such as fear, disgust and happiness [22]. It also plays a major role and is active during risky decision-making when not knowing the outcome [23].

1.2.4 Amygdala

The amygdala has an almond-shaped structure and is located deep within the temporal lobe. It is responsible for the communication of information between the hypothalamus and prefrontal / temporal cortices, addictive behaviour, but especially emotional memory; when processing threatening situations and responding to that with appropriate behaviours [19, 24]. Endocrine glands receive information from the amygdala to create hormones and fear responses [19].

1.2.5 Inferior Frontal Gyrus

The inferior frontal gyrus is located in the lateral and inferior surface of the frontal lobe and is active during speech and language processing. [25]

1.3 Aim of The Study

The video game industry is growing, and video games are a big part of many people's everyday lives, but it's an area that has not been studied enough to know how the biological effects. This study was done over two years, and new data on sleep disturbance was collected once every year to see the longitudinal effect of gaming on sleep. Previous studies have not investigated this longitudinally.

The aim of the study was to investigate how video games affect sleep and brain structure.

2 Method

The research included two questionnaires: The Sleep Disturbance Scale for Children (SDSC) and ABCD Youth Screen Time Survey (STQ), and magnetic resonance imaging (MRI) scans.

2.1 The Sleep Disturbance Scale for Children (SDSC)

The Sleep Disturbance Scale for Children is a scale designed to estimate sleep disturbance in adolescence and childhood. The scale is based on a questionary with 26 items based on sleep behaviour. Every item is a statement of a typical symptom of a major sleep disorder, see Table 1, and is answered by ranking the relatability from 1 to 5 scores. The total score is retrieved from the sum of all of the scores is an indication of sleep disturbance, where a higher value demonstrated severer symptoms.[26]

Table 1: The items included in the Sleep Disturbance Scale for Children. The items were ranked by relatability from 1 to 5 scores, where a higher value demonstrated severer symptoms.

Item	Explanation
1	Sleep duration
2	Sleep latency
3	Going to bed reluctantly
4	Difficulty in falling asleep
5	Falling asleep anxiety
6	Hypnic jerks
7	Rythmic movement disorder
8	Hypagogic hallucinations
9	Falling asleep
10	Night awakening
11	Difficulty in falling asleep after awakenings
12	Nocturnal hyperkinesia
13	Breathing problems
14	Sleep apnoea
15	Snoring
16	Night sweating
17	Sleepwalking
18	Sleeptalking
19	Bruxism
20	Sleep terrors
21	Nightmares
22	Difficulty in waking up
23	Tired when waking up
24	Sleep paralysis
25	Daytime somnolence
26	Sleep attacks

The 26 items were then sorted into six factors with similar characterization of sleep disturbance, see Table 2. Factor scores were calculated by summing scores from all items included in the specific factor, referring to how severe the symptoms of that factor are: a higher score was an indication of severer symptoms.[26]

Table 2: The six factors included in the Sleep Disturbance Scale for Children, and the items included in the factors. Each item in the factor was ranked by relatability from 1 to 5 points. The factor score was calculated by summing scores from the items included in the factor.

Factor	Explanation	Item
DIMS	Difficulty in initiating and maintaining sleep	1, 2, 3, 4, 5, 10, 11
SBD	Sleep Breathing Disorders	13, 14, 15
DA	Disorders of Arousallnightmares	17, 20, 21
SWTD	Sleep wake transition disorder	6, 7, 8, 12, 18, 19
DOES	Disorder of excessive somnolence	22, 23, 24, 25, 26
SHY	Sleep Hydrosis	9, 16

2.2 ABCD Youth Screen Time Survey (STQ)

ABCD Youth Screen Time Survey consists of a questionnaire with 6 questions, see Table 3, to determine the screen time of the participants of the study. Children were asked to indicate how long they were engaged in the following digital media use during the weekday and weekends. Seven potential answer choices included: none, $<$ 30 minutes, 30 minutes, 1 hour, 2 hours, 3 hours, and 4+ hours.

Table 3: Questions included in the ABCD Youth Screen Time Survey (STQ). Children were asked to indicate how long they were engaged in the following digital media use.

	Question
1	Watch TV shows or movies?
2	Wach videos (such as YouTube)?
3	Play video games on a computer, console, phone or other device (Xbox, PlayStation, iPad)?
4	Text on a cell phone, tablet, or computer (e.g. GChat, WhatsApp, etc.)?
5	Visit social networking sites like Facebook, Twitter, Instagram, etc.?
6	Video chat (Skype, FaceTime, etc.)?

2.3 MRI Scans

The T1 MRI-scans were taken while the child was watching a child-friendly movie in the scanner site. Cortical measures of volume of the total brain, hippocampus, amygdala and the surface area of medial prefrontal cortex, insula, and inferior frontal gyrus were calculated using Freesurfer 5.3.0 (`https://surfer.nmr.mgh.harvard.edu/fswiki/FreeSurferWiki`).

2.4 Multiple Linear Regression

A multiple linear regression, see Equation 1 is a statistical technique, where the outcome of a dependent variable (yi) is predicted from two or more independent variables ($xi1$, $xi2$,...xip), where $\beta 0$ is the y-intercept, $\beta 1$, $\beta 2$, and βp are the regression slopes and ϵ shows the residual error term.

$$yi = \beta 0 + \beta 1xi1 + \beta 2xi2 + ...\beta pxip + \epsilon \tag{1}$$

Two models with multiple linear regression: one to estimate video games' effect on sleep, and one to estimate video games affect on brain structure were made.

2.4.1 Model 1: Video games affect on sleep

The total sleep score and the scores from the factors (DIMS, SBD, DA, SWTD, DOES and SHY) where put into the regression separately as $y1$ values. Values from ABCD Youth Screen Time Survey (STQ), the participant's age, sex physical activity time and SES, see Table 6 in Appendix A, were put in the regression as $xi1, xi2, ...xip$, see Equation 1. The regression gave an output of the β-coefficient, P-value, and confidence interval . The β-coefficient, P-value, and confidence interval ([ ]) was analyzed. A positive β-coefficient means an increase in sleep score; worse sleep quality, and a negative β-coefficient indicates the opposite.

2.4.2 Model 2: Video games effect on brain structure

Model 2 was done and analyzed in the same way as Model 1, but the $y1$ values were replaced with the total brain volume, the volume of the hippocampus, amygdala, the surface area of the medial prefrontal cortex, inferior frontal gyrus, and insula, from MRI-scans. A positive β-coefficient means an increase in brain volume or surface area; video games affect the brain structure, and a negative β-coefficient indicates the opposite.

3 Results

At 9-10 years of age, 6,479 children were included for the analysis (age in months, mean [SD] = 118,6 [7,3]; boys, n (%) = 3373 (52%), girls, n (%) = 3106 (48%)),of whom 5,755 were included for the two-year follow-up.

The average Total Sleep Score (TST) by children at baseline was 36.6 [7.95] and 36.1 [8.58] at the two-years follow-up. The average total brain volume was 10711969,6 mm^3.

3.1 Sleep

At 9-10 years of age, video gaming was negatively associated with the total sleep score (TST), see Table 4 and Figure 1, both at baseline ($\beta = 0.8109$ [$0.611 - 1.011$] $P = 0.000$)

and two years later (β = 0.1958 [0.032 – 0.360] P = 0.019). There was also a negative association between video gaming and the subscale of DIMS (β = 0.3976 [0.308 – 0.488] P = 0.000), SBD (β = 0.0609 [0.031 – 0.091] P = 0.000), SWTD (β = 0.1101 [0.045 – 0.176] P = 0.001), DOES (β = 0.1877 [0.130 – 0.246] P = 0.000) and SHY (β = 0.0424 [0.013 – 0.072] P = 0.004). However, there was no association between video gaming and DA (β = 0.0128 [-0.010 – 0.035] P = 0.266). At two years follow up, there was a negative association between video gaming and the subscale of DIMS (β = 0.1193 [0.039 – 0.200] P = 0.004), SBD (β = 0.0281 [0.003 – 0.053] P = 0.030), and DOES (β = 0.0788 [0.020 – 0.137] P = 0.008). However, there was no association between video gaming and DA (β = 0.0038 [-0.014 – 0.022] P = 0.682), SWTD (β = 0.0239 [-0.029 – 0.077] P = 0.379), nor SHY (β = 0.0219 [-0.001 – 0.045] P = 0.057).

Table 4: Association between video games and sleep for children. The data are presented as beta coefficients [95 % confidence interval]. The data was adjusted to The Sleep Disturbance Scale for Children, age, sex, socioeconomic status (SES), physical activity, gaming time and MRI scanner sites. ***P<0.001, **P<0.01, *P<0.05.

Sleep variables	Baseyear (n=6479)	Two years later (n=5755)
Total Sleep Score (TST)	0.8109*** [0.611 – 1.011]	0.1958* [0.032 – 0.360]
DIMS	0.3976*** [0.308 – 0.488]	0.1193** [0.039 – 0.200]
SBD	0.0609*** [0.031 – 0.091]	0.0281* [0.003 – 0.053]
DA	0.0128 [-0.010 – 0.035]	0.0038 [-0.014 – 0.022]
SWTD	0.1101** [0.045 – 0.176]	0.0239 [-0.029 – 0.077]
DOES	0.1877*** [0.130 – 0.246]	0.0788** [0.020 – 0.137]
SHY	0.0424** [0.013 – 0.072]	0.0219 [-0.001 – 0.045]

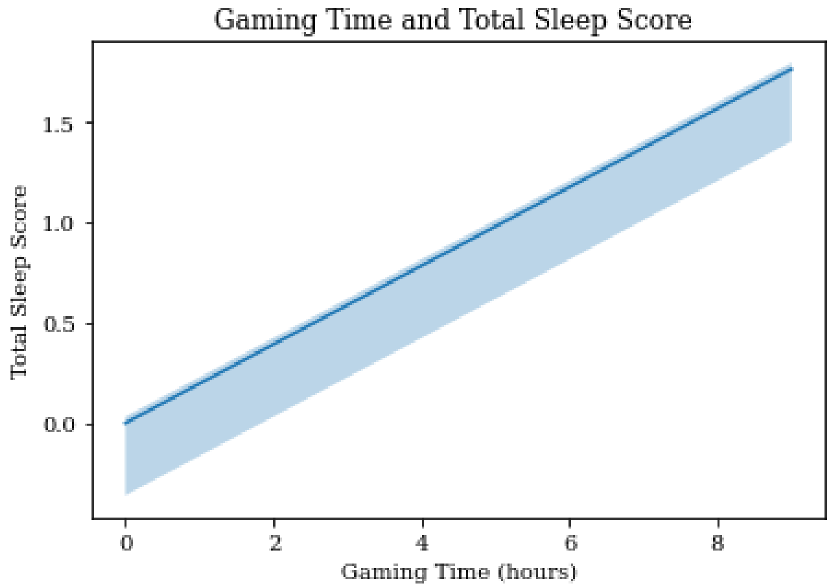

Figure 1: The corelation between gaming and total time score at the two-year follow-up. The regression slope shows the β-coefficient (β=0.1958) and the shaded area shows the 95% confidence interval [0.032 - 0.360].

3.2 Brain volume

A positive β-coefficient is an indication of a positive association between video games and brain structure, for a statistical significant association the P-value (P) must be under 0.05.

There was no statistical association between video gaming and the total brain volume (β = 298.7881 [-2703.526 – 3301.102] P = 0.845), nor the brain regions studied: volume of the Hippocampus, and Amygdala; and also the surface area of the Medial Prefrontal Cortex, and Inferior Frontal Gyrus, see Table 5. However, there was a positive association between video gaming and the surface area of the insula (β = 11.4735 [1.682 – 21.265] P = 0.008), see Table 5 and Figure 2.

Table 5: Association between video games and brain regions for children. The data are presented as beta coefficients [95% coefficient interval]. The data adjusted to brain volume, age, sex, socioeconomic status (SES), physical activity, gaming time and MRI scanner sites. ***P<0.001, **P<0.01, *P<0.05.
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Brain region	Beta Baseyear (n=6479)
Total Brain Volume	298.7881 [-2703.526 – 3301.102]
Hippocampus	-4.6679 [-25.835 – 16.499]
Medial Prefrontal Cortex	8.2742 [-79.512 – 96.060]
Insula	11.4735* [1.682 – 21.265]
Amygdala	-1.4674 [-12.142 – 9.207]
Inferior Frontal Gyrus	-1.8967 [-16.344 – 12.550]

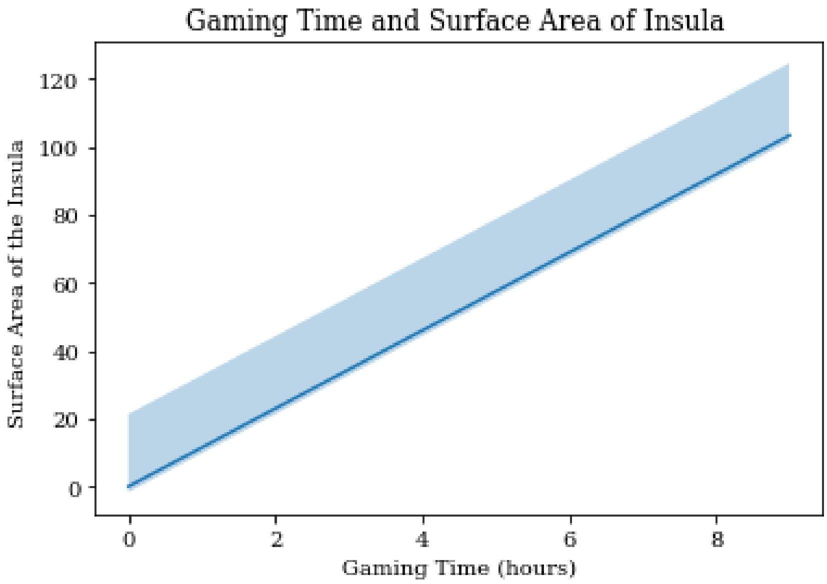

Figure 2: The corelation between gaming and the surface area of Insula. The regression slope shows the β-coefficient (β=11,4735) and the shaded area the 95% confidence interval [1.682 - 21.265].

4 Discussion

The results indicate that video gaming effect sleep negatively, even in long term, see Table 4. Crossectionally, video gaming was associated with larger surface area if insular, see Table 5.

4.1 Video games effect on sleep

The insula is responsible for the autonomic nervous system which regulates physical processes that are not voluntary such as blood pressure, heart rate, respiration, and the activity in certain glands. Previous studies have proved that video games change these factors (id est, heart rate, respiration and blood pressure) so they increase. These suggest that the insula is active during video gaming. When the insula is active, it can affect hormone production as hormones are produced in adrenal glands. This has been shown in a previous study on mice, where damage to the insular led to a decreased production of testosterone [27]. A change in the concentration of certain hormones during the 24-hour cycle, disturbs the circadian rhythm. By increasing the production of cortisol and reducing the production of melatonin, sleepiness will decrease, which makes it harder to fall asleep during nighttime. Disturbance in the circadian rhythm will affect other hormones and chemical substances that can affect sleep and sleep quality, when tricking the body into cellular functions that are not meant to happen during that time of the 24-hour cycle. It can be observed that video gaming over time worsens sleep quality, see Table 4, which indicated that the circadian rhythm and the insula get affected when the gaming time increases.

The autonomic nervous system can be divided into the sympathetic nervous system and the parasympathetic nervous system. The sympathetic nervous system sends signals to the body on how to respond rapidly when registering stressful and dangerous situations by sensory impression. Video games often contain graphics, sounds and experiences that are stressful, which activates the insula and responses: to produce hormones that boost alertness and heart rate. This will increase SOL - the time it takes to fall asleep and shorten total sleep time. Based on this, it is suggested that video games might influence insular, which might be associated with negative sleep.

4.2 Video games effect on brain

No association between video gaming and the total brain volume, nor brain regions except the insula was found. A possible explanation is that it takes time for the brain structure to change, and that a follow-up study is necessary. Although effects on the insula shown as an increase in the area could be found. A possible explanation is that the insula influences other brain networks: DMN (id est, Medial prefrontal cortex) and CEN (id est, prefrontal cortex) in auditory and visual conditions (id est, video games), and could therefore be more influenced as it must be more active in passing on the information to the other brain regions.

The increased area of the insula is a result of high activation of it when video gaming. Video gaming often involves risky decision-making under time pressure, the anticipation of what one's move will lead to and other emotional stimuli such as happiness and fear, audio, and visual experiences, all of which the insula is active. This increases the surface area of the insula and could therefore affect the hormone production and disturb sleep both cross-sectionally and longitudinally. However, a mediation analysis to test whether insular mediates the relationship between video games and sleep was not performed.

4.3 Future studies

To make a conclusion about the effect of video games on the brain, a longitudinal study needs to be done in the future. Additionally, future studies should also investigate how altered brain structure mediates the relationship between video games and sleep.

4.4 Conclusion

Video gaming does not alter brain structure but affects sleep in children. A long-term study is warranted for a better conclusion on brain changes.

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A Con-founders included in statistical analysis

Table 6: Variables included in the models for the research. The data are presented as mean [standard deviation, σ], n or [%].

Variable	Mean [σ] or n [%]
Age in months	118.6 [7.3]
Number of boys in the Sleep Disturbance Scale for Children Base Year	3373 [52%]
Number of girls in the Sleep Disturbance Scale for Children Base Year	3106 [48%]
Number of boys in the Sleep Disturbance Scale for Children Year 2	3031 [53%]
Number of girls in the Sleep Disturbance Scale for Children Year 2	2724 [47 %]
Number of MRI-scans from boys in the Base Year	3373
Number of MRI-scans from boys in the Base Year	3106
Gaming time in hours per day	0.96
Amount of scanner sites	22